THE SCHRAGE MACHINE AS A SELF-EXCITED ASYNCHRONOUS GENERATOR

D. D. BLAIR
AND
D. M. WYNNE

1953

THE SCHRAGE MACHINE AS A SELF-EXCITED ASYNCHRONOUS GENERATOR

-

D. D. BLAIR

D. M. WYNNE

THE SCHRAGE MACHINE

AS A SELF-EXCITED ASYNCHRONOUS GENERATOR

by

Donald D. Blair

and

Donald M. Wynne

Lieutenants, United States Navy

Submitted in partial fulfillment
of the requirements
for the degree of
MASTER OF SCIENCE
in
ELECTRICAL ENGINEERING

United States Naval Postgraduate School
Monterey, California
1953

This work is accepted as fulfilling

the thesis requirements for the degree of

MASTER OF SCIENCE
in
ELECTRICAL ENGINEERING

from the

United States Naval Postgraduate School.

PREFACE

This study was conducted in order to investigate the characteristics of the Schrage machine when operating as a self-exciting asynchronous generator. From a theoretical study of the vector diagrams of the Schrage motor, herein has been developed and presented the vector diagrams for generator action for subsynchronous, subsynchronous to supersynchronous, and the supersynchronous modes of operation. The generator characteristics, control problems, and the ability of the machine to carry lagging loads were investigated for indications of possible practical application in this type of operation.

The work was conducted from November 1952 to May 1953 at the United States Naval Postgraduate School, Monterey, California.

Grateful acknowledgements are given to Professors C. V. O. Terwilliger and A. E. Vivell of the Electrical Engineering Department for their invaluable assistance and encouragement.

Donald D. Blair

Donald M. Wynne

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

TABLE OF SYMBOLS AND ABBREVIATIONS

emf	electromotive force
E_1	emf developed in primary by main flux
E_2	secondary induced voltage
E_a	adjusting winding voltage
I_1	total primary current
I_2	total current flowing in secondary
mmf	magnetomotive force

* * * * * *

ADDITIONAL SYMBOLS AND ABBREVIATIONS USED IN FIGURES

Avg	average
f, freq	frequency
N_1	primary turns
N_2	turns in secondary
N_a	number of turns of adjusting winding spanned by brushes
I_2N_a	ampere-turns developed by secondary current flowing through adjusting winding
I_mN_m	total resultant magnetizing ampere-turns developed in machine
PF	power factor
Rel.	relative
R_1	resistance of primary
R_2	total resistance of secondary circuit
Rot.	rotation

Syn.	synchronous
s	slip
V_1	terminal voltage of machine
X_{2s}	reactance of secondary at slip s

SUMMARY

The objective was to investigate the self-excited asynchronous generator action of the Schrage machine. To obtain self-exciting action a 90° phase shift of the adjusting voltage was accomplished by a brush shift and a rewiring between the adjusting winding and the secondary. This permitted the forcing of an exciting current through the secondary and enabled the machine to self-excite and to generate while carrying lagging power factor loads.

Characteristic curves for various fixed brush settings were taken at selected lagging power factors. The machine was tested in independent operation and in parallel, in order to investigate the control problem and to determine the efficiency of the generator.

The investigation showed the machine to be able to initially self-excite; to be able to carry loads at lagging power factor; and to be able to be controlled in voltage and frequency under changing loads, although precise control was difficult. Further, the machine was shown to be inefficient when compared with conventional synchronous generators.

INTRODUCTION

The operation of the Schrage machine as a motor has been well investigated in the past. The machine is ingeniously designed and very versatile, being capable of variable speed and power factor motor operation. In consequence of its versatility and complex inter-relationship of its component parts, it has been, in the past, the object of many interesting studies.

The characteristics of the machine as a motor at different brush settings and under different types of loading have been previously obtained. Since its invention by Schrage in 1912, Arnold (1926) developed the vector diagram for the machine. Conrad, Clarke, and Zweig (1941) (1) have developed and enlarged upon a method of predicting performance by circle diagrams. Bhattacharyya (1949) (2) developed the vector diagrams for the synchronous, and supersynchronous operation and also the diagram for the motor running at supersynchronous at no load being loaded to subsynchronous. No previous investigation of the machine as a generator is known to the authors.

Conrad (1) in his work on the motor action of the machine did mention that in generator action the machine would be capable of delivering lagging reactive power, but he stated that this was so when excited from a synchronous source.

To determine that this machine could self-excite and independently carry lagging loads was one of the main purposes of the investigation. The machine by its past proven performance as a power factor motor had demonstrated its ability to draw a leading current from the line, in contrast to the lagging current drawn by an ordinary induction motor. Similarly, the machine was reputed to be able to furnish its own exciting current when operated as an asynchronous generator, as opposed to an ordinary induction generator which must (a) be operated in parallel with synchronous generators which would furnish the exciting current or (b) furnish power to a leading power factor load.

In obtaining the characteristic curves under various conditions and loading, there was no small hope that perhaps this machine would show characteristics that were more admirable than those induction generators operating with capacitor or similar schemes of self-excitation. Just how to obtain and present intelligently the characteristics of such a machine with its many variables of speed, frequency, brush spread, voltage, and power factor, presented a challenge. Then, beyond the matter of its inherent characteristics came the last question: the manner of control of such a machine in voltage and frequency when operating independently of a distribution system.

CHAPTER I

THE SCHRAGE MACHINE AS A MOTOR

The Schrage machine is ordinarily a variable speed a.c. commutator motor, that obtains its speed control and also power factor correction by impressing a controlling a.c. voltage on its secondary. As is well known, the speed of a wound-rotor induction motor may be controlled by inserting resistance in the secondary. The Schrage motor replaces this drop across the resistor by a voltage which it inserts into the secondary from the adjusting winding. This eliminates the I^2R loss of the speed-adjusting resistors and also enables the machine to obtain supersynchronous speeds and power factor correction.

The interjected voltage, which will henceforth be called the adjusting voltage, must be of slip frequency. How the machine produces a voltage at slip frequency at all speeds is the unique part of the machine. Referring to figure 1, the primary winding will be considered first. It is seen the primary of the machine is on the rotor of the machine and the connections brought out to the slip rings. The three phase primary winding on the rotor will set up a field which will rotate at synchronous speed with respect to the rotor. If, say, the phasing was in such a direction that the field rotated in a counter-clockwise direction with respect to the

rotor, the rotor then would rotate in a clockwise rotation, and the field then would cut the secondary winding at slip frequency as in an ordinary induction machine; see figure 2. To an observer on the stator, the field would appear to be rotating in a counter-clockwise direction at slip frequency. The synchronous field still cuts the rotor conductors at synchronous speed, as the primary winding is on the rotor.

On the rotor is wound also a regular lap winding in the same slots as the primary. This is called the adjusting winding. This winding is brought out to the commutator. The voltage developed by the adjusting winding is picked off by the pairs of brushes on the commutator.

The secondary winding is a regular three phase winding similar to that of a secondary on a wound-rotor induction motor except that it is wound on the stationary part of the machine and it is not brought to a common connection, but rather it has the ends of each phase brought out and connected across the brushes of the commutator.

That the voltage produced across the brushes of the adjusting winding is actually a voltage of slip frequency can be explained in several ways. One way to explain it is to consider that the brushes see through the homogeneous lap winding an identical electrical connection, regardless of the position of the rotor, and also regardless of the speed at which the rotor is turning. It is, then, as if the

conductors between the brushes were actually stationary in space as far as the electrical connection between the brushes is concerned. One could consider, then, that the field which is rotating in space at slip frequency cuts the electrical connection between these stationary brushes at slip frequency and produces a voltage at the brushes of slip frequency.

The amount of adjusting voltage impressed on the secondary can be varied by increasing or decreasing the separation, or spread, of the brushes. The voltage induced in both the secondary and adjusting windings can be seen from figure 2 to be in the same direction. However, it can be seen that by the electrical connections E_a is normally made to buck E_2 by 180°; figure 2 and 3.

The current flowing in the secondary will be determined by the resultant emf impressed upon it and by the impedence of the circuit; and the current will always lag this resultant voltage by an angle determined by the impedence of the secondary (the reactance of which, of course, varies with the slip). In figure 3, it can be seen that the resultant voltage is vector oa. At all times the in-phase component of current flowing in the secondary will be of the amount required by the torque demands placed upon the motor by the load. If E_a were increased in figure 3, by a further spread of the brushes, the resultant voltage would be temporarily reduced and the load torque would reduce the speed of the

motor until the greater slip increased E_2 sufficiently to produce again a resultant voltage great enough to cause the required amount of in-phase current to flow. This ability to change the slip for a given load is the method by which the speed of the motor is controlled. If the brushes were crossed, and E_a were made to initially assist E_2, the increased current would cause the motor to accelerate. This increase in speed would decrease E_2 because of a decrease in slip; or if the load were light enough, actually reverse the direction of E_2 by the machine going into supersynchronous speed. (At supersynchronous speeds the flux would cut the secondary conductors in the opposite direction, see figure 4a. The flux is still cutting the conductors of the adjusting winding at synchronous speed in the original direction and the same magnitude of E_a is developed in the same direction as before). This increase in speed would continue until the resultant voltage, and hence the in-phase current, would be brought back down to a value to bring the motor back into torque equilibrium with the load. See figure 4b for supersynchronous speed vector diagram. Thus, it is seen that the motor can be made to run at subsynchronous or supersynchronous speed.

The phase position of E_a with respect to E_2 can also be altered by shifting the brushes together around the commutator. As can be seen from figure 5, which is a diagram for subsynchronous speed operation, a 90° shift of

the adjusting voltage in the direction indicated would cause the resultant voltage (and hence the current which lags that resultant by a fixed angle) to be advanced in time phase, thereby improving the power factor of the motor. This particular shift was accomplished by rotating the brushes 90 electrical degrees against the direction of rotation of the rotor. The portion of the adjusting winding now spanned by the brushes would be cut by the flux 90 electrical time degrees later than before, and the direction of E_a in diagram 5 would be retarded 90 electrical time degrees into the position shown.

Looking at figure 4b for the supersynchronous case, it can be seen that if a component of voltage were impressed along line ox it would tend to advance the time phase of the resultant voltage oa, and hence the current. However, if you were to shift E_a for power factor improvement at supersynchronous speeds you would have to insure that you retained some speed component of E_a in the proper direction in order to maintain the supersynchronous speed. That is, E_a would have to be somewhere in the third quadrant of the figure. This position could be obtained most easily by a small shift of the brushes in the direction of rotation; keeping the brushes electrically crossed, of course. Similarly, it can be said that power factor improvement at subsynchronous speed can be obtained by a position anywhere from line ox into the fourth quadrant.

In summary, it can be seen that power factor improvement is obtained as long as the adjusting voltage lies within quadrants three or four. Whether the voltage is in quadrant three or four merely determines the direction of the speed component involved. Furthermore, whether you lag the brushes or advance them with rotation is merely a question of which way you may most conveniently obtain the position desired. For example, one could obtain the supersynchronous speed position mentioned above by the alternate method of shifting them against rotation more than 90° and keeping them uncrossed; thereby, obtaining the third quadrant position desired. See Appendix I for a more detailed discussion of the alternate ways of setting brushes for the various speed settings.

To avoid too lengthy a discussion on how the motor controls speed and power factor the foregoing has necessarily been very brief. The reader is referred to the Bibliography for sources with more detailed descriptions.

CHAPTER II

THE SCHRAGE MACHINE

AS A SELF-EXCITED ASYNCHRONOUS GENERATOR

The first step in determining how to produce a self-exciting asynchronous generator is to consider why an ordinary induction generator does not self-excite. Another way of saying this is that we must first see why an ordinary induction generator needs to draw a lagging current from the line (i.e. work into leading loads), before proceeding to discuss our generator which does not.

Taking the circle diagram of the induction machine in figure 6, we see that point (a) represents motor action and point (b) generator. In both cases the machine must have the same reactive component of current, oc. As the prime mover is unable to affect the reactive or wattless current flowing in the generator, it must get this current from the line. A motor put across the line develops a flux which enables the motor to develop torque and generate a back emf against the impressed voltage. It necessarily requires a lagging component of current to act as a magnetizing (or exciting) current for that flux. Now, if the machine is to act as a generator it will still require the same flux in order to develop that same generated emf. (In generator action the primary emf stays in the same direction as before.

The current, however, being at an angle of less than 90° with it for generating and more than 90° for a motor.) In order to maintain that flux we have seen that the ordinary induction generator then, perforce, must draw essentially the same exciting current from the line as before.

The flux existing in the air gap of an induction machine is set up by the vector addition of the mmf's of constituent windings. Heretofore, ordinary induction generators have been kept generating, when operating independently, by assuring that they always look into leading loads. This could be stated as a case wherein the ampere-turns in the primary are in the proper magnitude and phase to produce a resultant mmf which maintains the proper flux. This case could be described by saying "the exciting current flows in the primary". Now, with two windings, the primary and secondary, it is intuitively obvious that if we could by the use of an impressed voltage send a current of the proper phase through the secondary we could "excite" the machine from the secondary, and maintain the flux in that way. Furthermore, by steadily increasing this reactive voltage as we load down the machine we could overcome the demagnetizing effect of the lagging load current in the primary, and maintain the voltage. We, then, would have an induction generator which would, contrary to its usual characteristics, operate into unity power factor or lagging power factor loads.

The Schrage machine acts as a self-exciting asynchronous generator and carries lagging loads by sending the exciting current through the secondary by use of an impressed voltage of the proper phase and magnitude from its adjusting winding.

The Schrage motor, with the proper rotation and separation of the brushes, can operate as a power factor motor. It can draw either lagging or leading components of current from the line. The ordinary induction machine, generator or motor, must always draw a lagging current. Now, by inference, if the Schrage machine were set up in such a way that it did not draw a lagging current as a motor, then it should be able to act also as a generator at that same setting without drawing a lagging load from the line. This proves to be true in the investigation. But before going on to the results of the investigation, the vector diagram for the generator will be developed from the vector diagram as previously given by Arnold for the motor.

Figure 7 is the subsynchronous speed, motor vector diagram with the adjusting voltage leading E_2 by 90^o, by having retarded the brushes 90 electrical degrees against the direction of rotation of the rotor. Increasing E_a advances the time phase of I_2, which when reflected into the primary improves its power factor. Now, if we were to take the vector diagram and apply it to the generator case,

figure 8, we would have to first reverse the direction of E_2, because in generator action the machine would be speeded up to supersynchronous speed. The machine runs at sub-synchronous speed as a motor because there is no appreciable speed component of adjusting voltage. There seems, however, to be a small speed component due to the fact that the total emf developed in the primary conductors (and hence in the adjusting winding which lies in the same slots) does not lie at right angles to the main flux, because of the effect of primary leakage reactance. The adjusting voltage, then, being shifted at right angles to its usual position, does not lie precisely at 90° with E_2.

Figure 8 is the case of the machine generating while the primary circuit has a lagging power factor load. Figure 9 is a diagram of the mmf's for this case.* It can be seen that the lagging power factor primary load tends to demagnetize the machine. This indicates that with increasing load at fixed lagging power factor it would be necessary to keep increasing the reactive component of the secondary current by increasing brush separation in order to maintain voltage. Also, with a given magnitude of current, successively larger lagging angles require greater spread. Both

* This mmf diagram was developed from a similar one for the motor contained in reference (6).

of these predictions are born out. A further prediction could be that perhaps if the direction of I_1 were placed somewhere along the line of E_1 (i.e. at near unity power factor and at right angles to the flux) an increase in load could be taken at fixed brush spread without an appreciable drop in voltage; that is, without any demagnetizing effect from primary current. Laboratory runs made with independent operation at unity power factor with fixed brush spread show an almost completely flat voltage regulation curve. See figures 18 to 21. Of course, this is a rather crude prediction, ignoring several factors, but nevertheless this is a correlation. In a similar manner you could predict the rising voltage characteristic that the machine has with leading loads.

In summary, it would be best to repeat that the proper position of the brushes for self-excitation is the one which will give the machine when operating as a motor a leading power factor. Chapter III tells how the brushes were actually set for generator action in this investigation.

The secondary circuit vector diagrams developed for generator action at various speed settings of the machine are figures 10, 11 and 12. For figure 10, notice that as the machine is brought closer to synchronous speed E_2 is reduced. E_a, of course, is a constant voltage for a given brush separation. In figure 11, the machine running as a

motor at subsynchronous speed is forced to run at super-synchronous speed in order to generate; reversing the direction E_2. In figure 12, which is the diagram for the supersynchronous case, it can be seen that by driving the machine above its speed setting, the induced emf E_2 is made larger than the previously larger speed component of E_a, bringing about the generator action.

CHAPTER III

EXPERIMENTAL PROCEDURE AND CHARACTERISTIC CURVES

The machine used for this investigation was a General Electric BTA motor with the following name plate data:

General Electric type BTA, model 75E748G4

6 Poles, Serial Number 5581876

220 Volts, Sec. Amps 42, Cycles 60, 3 Phase

		Speed
HP 5	17.6 Amps	1600
HP 2.5	14.0 Amps	800
HP 1.67	12.0 Amps	533

A shunt field d.c. motor was used as the prime mover. The machine was set up to operate as a self-excited asynchronous generator by adjusting it so that the adjusting winding voltage was placed at a 90° phase difference with the secondary induced voltage in order that the reactive component of current in the secondary could be controlled. This adjustment was first accomplished at the terminal board of the machine. The electrical connections from the adjusting winding brushes were reconnected to the secondary phases next adjacent in the direction of the rotation of the rotor. This effected a 120° retardation in time phase of the adjusting voltage with respect to voltage induced in the secondary. The brushes were then shifted 30 electrical degrees around

the commutator in the direction of rotation by slipping the brush rigging with respect to its supports. (The bolt holes for the brush rigging on this machine were already slotted for this purpose.) This, then, advanced the phase of the adjusting voltage 30° and accomplished the desired 90° position. The reader is referred to figure 30 for a diagram of the voltage relationships so accomplished.

The actual phase displacement between these two voltages was then measured by the use of an oscilloscope and lissajous figures. The secondary connections were opened and one phase of the secondary was placed across one set of plates of the oscilloscope, and the electrical connections from the corresponding set of brushes were placed across the other set of plates. The machine was turned over by the prime mover at rated speed and line voltage was applied to the primary. (It was necessary to rotate the machine during this measurement in order to limit the current in the windings which would be short circuited under the brushes on the commutator.) The resulting lissajous figure was a fairly good circle, indicating an approximate 90° phase displacement between the voltages. However, spurious voltages caused by commutation obscured the picture on the scope somewhat, and thus the perfection of the circle was in doubt. The machine was then stopped and all the brushes were lifted from the commutator and probes were used to pick off the

adjusting winding voltage. By exploring with the probes, it was found that if the brushes were moved approximately one commutator segment further a better circle was developed on the scope. This indicated that the voltage was actually at an angle slightly greater than 90°. The construction of the machine did not allow for any greater movement of the brushes. So long as there was a component of adjusting winding voltage at right angles to the induced voltage of the secondary which would enable the investigators to control the reactive current, and hence accomplish the self-excited generator action, the necessary conditions were fulfilled. As the presence of a small speed assisting component would merely alter slightly the speed at which the generator would operate, no further adjustments were made. This is the reason why the no load speeds of the generator as indicated in the graphs are above synchronous speed.

Next, a measurement of adjusting voltage versus brush separation was made by placing voltmeters across the brushes. A plot of these voltages was made, figure 13, and an arbitrary numbering system for indicating brush spread was set up to correspond to various voltages; as indicated on this aforementioned graph, and as used on other curves. Brush separation was finely controlled by a worm and gear attachment connected to the lever that ordinarily controls brush spread on this machine.

To meter the machine in its various runs an industrial analyser was placed on the output terminals, and ammeters were placed in the secondary circuit. To load the machine a set of resistor banks connected in wye were used for the main in-phase load, and a synchronous motor running at no load was connected in parallel to the banks to control the power factor by varying its excitation. The frequency of the output was measured by a stroboscope connected to line frequency and shined on the shaft of the synchronous motor; except for a few runs not made at 60 cycles, at which time a frequency meter was used.

It was found that the machine could initially self-excite and build up voltage if the brushes were placed at maximum separation in the uncrossed direction, which is the normal subsynchronous speed direction. It was necessary, as soon as the machine began to build up, to quickly reduce the amount of separation before excessive secondary currents were produced. The first thing noticed about the machine was that, in order to maintain rated voltage at no load, it was necessary to have about 40 amperes flowing in the secondary. It can be seen from the name plate data that the rated secondary current is 42 amperes. It was found throughout the investigation that this rated value had to be greatly exceeded in order to use the machine at rated voltage with an appreciable lagging power factor load; see figure 23.

This indicates one obvious feature that would have to be redesigned if the machine were to be used practically as a generator.

After the machine was set up and found to be capable of self-excitation, various runs were made. First, a few runs were made at fixed brush spread and constant r.p.m. in order to observe the inherent frequency and voltage regulation of the machine. See figures 14 to 16. It was decided that all subsequent runs be made maintaining 60 cycle output frequency. A series of runs were made at different brush spreads at various selected lagging power factors. This produced a series of voltage regulation curves which can be seen in figures 17 to 22. The investigators were primarily interested in the ability of the machine to carry lagging power factor loads so only one run was made at leading power factor. The reason there is not a complete range of lagging power factors indicated on the voltage regulation curves for the various spreads is because of limitations of the machine. In the case of large spreads, too small of a power factor angle on the load results in excessive secondary currents in the machine. In the case of small spreads, the machine stops generating after the power factor angle becomes appreciable. The power factors below .7 lagging were not investigated because of time limitations, and because it was thought that such power factors are not commensurate with the usual practical loads that are encountered.

In order to test the efficiency of the machine and investigate its control problems, a series of independent runs were made at constant power factor load and maintaining voltage and frequency by continuously adjusting brush spread and speed during the run. The resultant curves are figures 23 to 26.

The efficiency curves for the generator, figure 26, were computed by first obtaining the losses of the d.c. motor prime mover. The stray power loss method was used, including an actual measurement of the d.c. motor's armature resistance. Having deducted the total losses of the d.c. machine from the input, the overall efficiency of the generator was its measured output divided by its computed input.

CHAPTER IV

INDEPENDENT AND PARALLEL OPERATION

Operating as an independent generator, the output voltage was controlled by continuously changing the brush separation with changes in load. As the output frequency tended to change with the changes in slip for various loads, the speed of the prime mover had to be continuously adjusted in order to maintain frequency.

Several runs were made at selected lagging power factors in order to investigate this control problem. As the machine was loaded every effort was made to maintain frequency and voltage at each incremental change in load by the methods mentioned above. A tedious control problem was encountered. The machine, without any adjustment of its controls, has a tendency when loaded down at lagging power factor loads to drop off in frequency and voltage. If at any point an attempt is made to bring frequency back on by increasing the speed of the prime mover, an accompanying small rise in voltage is noted. This accompanying rise in voltage, at .9 power factor or less, was found to be insufficient to keep the voltage up to its original value. Therefore, it was found necessary to increase the spread of the brushes to bring the voltage back up to its starting value. An increase in spread increases the secondary current which increases the load on

the machine, in turn causing the speed and frequency again to drop. An increase in brush spread causes the adjusting voltage to force more reactive current through the secondary, thereby demanding a greater torque from the prime mover; even though the external load may not have changed in consequence of the resulting increased voltage. This interplay of the controls makes necessary a very tedious adjusting and readjusting of both the speed of the prime mover and brush separation in order to maintain both voltage and frequency. So delicate is the brush setting in regard to the voltage and its effect on speed that it was often necessary to spend five minutes before the proper voltage and frequency were regained. Figures 23 to 26 are the curves for the independent runs.

If the machine is placed in parallel with a large system, the voltage and frequency are naturally fixed. In independent operation the output power factor is fixed by the load and the voltage controlled by brush spread. In parallel operation, the output power factor is controlled by brush spread. Several parallel operation runs were made imposing the condition of constant output power factor on the machine. It was found that the brush spreads necessary to maintain a given lagging power factor increased with load and were nearly identical to the spreads found in the independent runs necessary to maintain the same voltage at that power factor. Figures

23 to 26 represent the behavior of the machine when operating in parallel as well as when operating independently. Control of power factor by this method is quite simple and fine adjustments can easily be made.

CONCLUSIONS

This asynchronous generator is of considerable scientific interest because of its ability to self-excite and deliver lagging reactive power. By simply altering the brush spread the voltage can be controlled when the machine is operating independently, and the power factor controlled when operating in parallel. Frequency can be controlled by changing the speed of the prime mover. The machine, like all induction generators, does not have to be synchronized before being paralleled. The voltage of the machine, however, is very difficult to control to a precise value because of the large effect on voltage of a very slight change in brush separation. The machine is highly inefficient, especially when compared to a comparably sized synchronous generator. The very large secondary currents necessary to maintain the flux of the machine while it is working into lagging loads, causes a large I^2R loss in the secondary circuit and a large power loss across the brushes. This required secondary current greatly exceeds the rated amperage of the machine as presently designed for motor operation.

Although the investigators encountered no commutation difficulties unless the machine was greatly overloaded, nevertheless the presence of a commutator and six brushes must be considered a disadvantage. The machine is expensive compared to a synchronous generator of similar rating.

If an application should arise in which it would be more desirable to use an induction generator rather than a synchronous one, this machine should be considered because of its ability to carry lagging loads without the aid of any external circuitry. Provided, of course, the expense of the machine and its relatively low efficiency are not overriding factors.

BIBLIOGRAPHY

1. Conrad, A. G., Zweig, F., and Clarke, J. G., Theory of brush shifting a.c. motor, I, II, III, and IV, Electrical Engineering (AIEE Trans.) Vol. 60, pp 829-836, July - December 1941; Vol. 61, pp 502-512, July-December 1942.

2. Bhattacharyya, H. P., Studies of Schrage three phase shunt commutator motor I, II, and III. Indian Journal of Physics; Vol. 23, pp 459-464, November 1949; Vol. 24, pp 119-124, March 1950.

3. Liwschitz-Garik and Whipple, Electric Machinery, Vol. II.

4. Teago, F. J., The Commutator Motor.

5. Bryant and Johnson, Alternating Current Machinery.

6. Dennison, B. C. and Karapetoff, V., Experimental Electrical Engineering, Vol. II.

7. Langsdorf, A. S., Theory of Alternating Current Machinery.

8. Adkins, B. and Gibbs, W. J., Polyphase Commutator Machines.

APPENDIX

SETTING BRUSHES FOR POWER FACTOR IMPROVEMENT IN MOTOR OPERATION AND FOR SELF-EXCITED GENERATOR ACTION

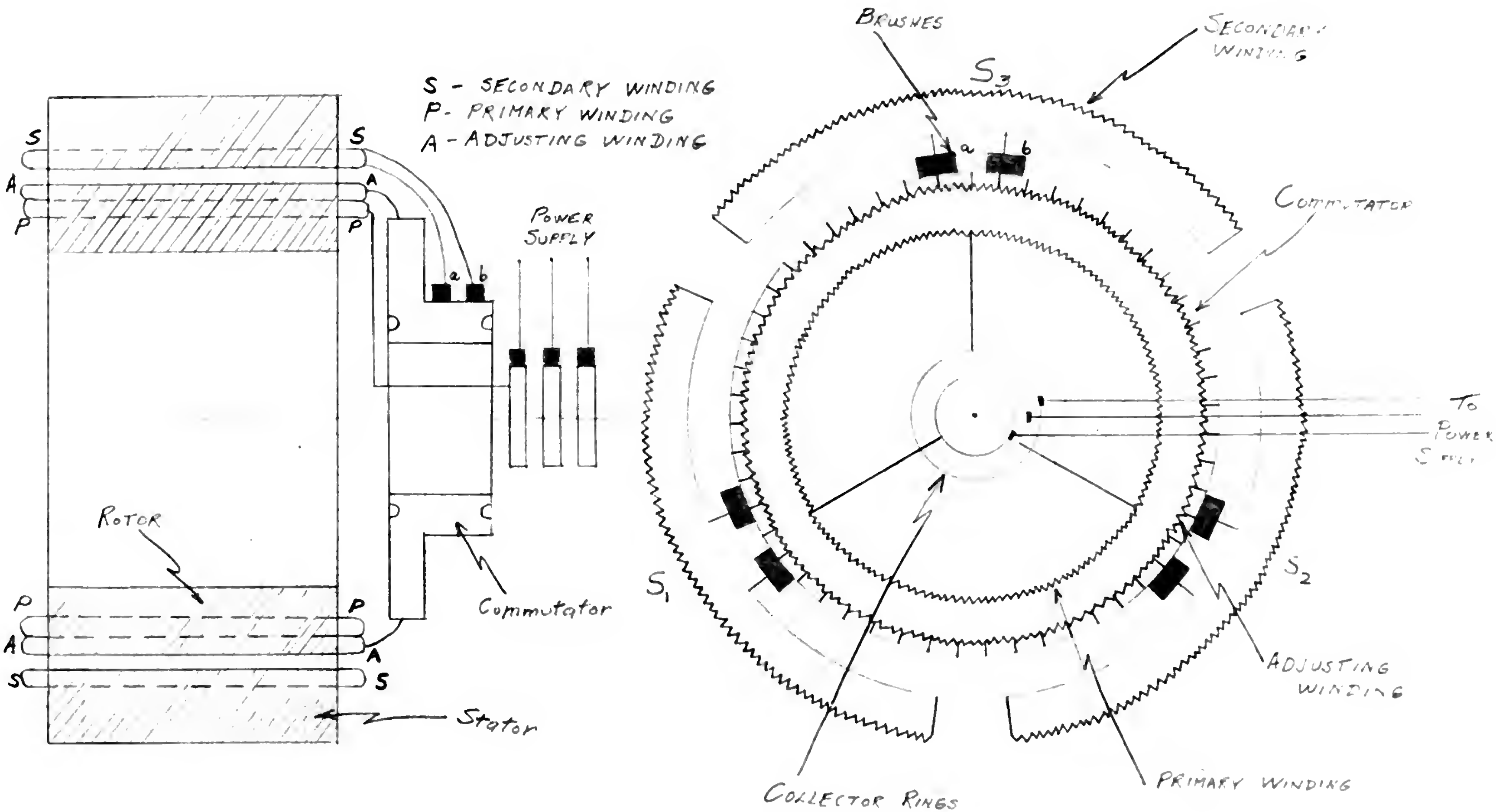
Various rules of the thumb on how to shift the brushes for power factor improvement for the motor have been previously published, but the authors will give below a little more generalized development in order to take care of any confusion that might result from crossing the brushes. Recall the fact that the brushes are capable of being crossed electrically. That is, there is a "slow" or uncrossed position, and a "fast" or crossed position.

To improve the power factor of the Schrage motor at subsynchronous speeds and to set it up for self-exciting generator action the brushes may be shifted against the direction of rotation of the rotor (keeping brush separation setting in the uncrossed or "slow" speed position on the brush speed indicator dial). That is, in figure 27 the E_a voltage should be in the fourth quadrant. This also could be accomplished by advancing them from 90 to 180 degrees and crossing the brushes. If you did this you would find yourself at an actual subsynchronous setting with the dial reading "supersynchronous" or "fast" position! If you wished the machine to operate at about its normal synchronous speed the brush voltage should be at 90° (no speed component).

This would require the brush voltage to be along line oa in figure 28, which could be obtained by retarding the brushes 90° and spreading them directly apart (in "slow" speed direction). You could get this setting equally as well by advancing them 90° and crossing them (spreading brushes toward "fast" part of the dial).

For supersynchronous operation the proper quadrant is indicated in figure 29. This setting could be obtained most easily by shifting from 0 to 90 degrees in the direction of rotation and keeping the brushes crossed. Alternately, rotate them against the direction of rotation from 90° to 180° and keep the brushes spread directly apart, or in the "slow" speed part of the dial.

When it is considered that one can get an effective phase shift of 120° or 240° in either direction by reconnecting the adjusting winding to different phases of the secondary, it is seen, after a little study, that any desired phase shift can be accomplished without having to physically shift the brushes more than 30 electrical degrees around the commutator.



THE SCHRAGE MACHINE FIG. I

FIG 2
SUBSYNCHRONOUS SPEED
MOTOR

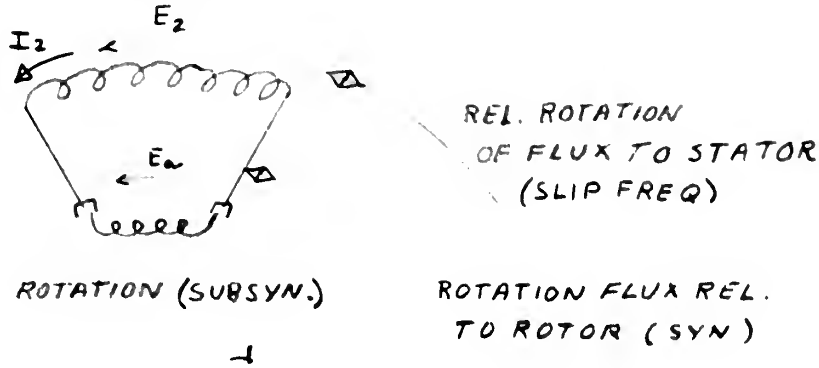


FIG 3
SUBSYN. SPEED MOTOR

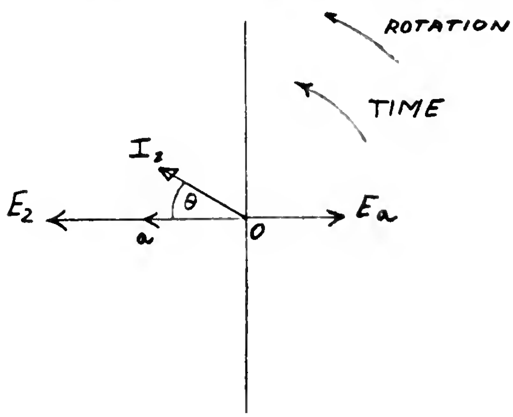


FIG. 4b
SUPERSYN. SPEED MOTOR

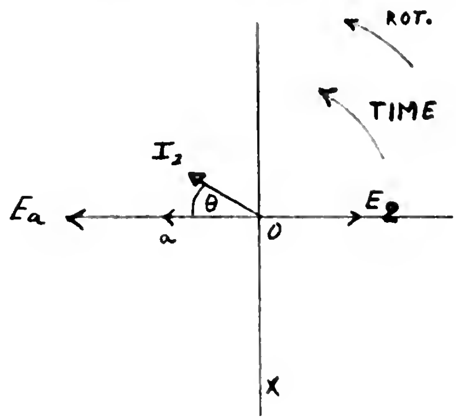


FIG 4a
SUPERSYNCHRONOUS SPEED
MOTOR

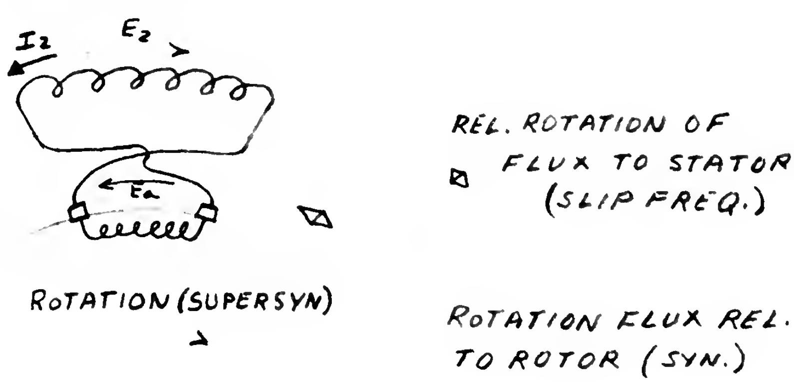


FIG 5

POWER FACTOR IMPROVEMENT SUBSYN. SPEED (MOTOR)

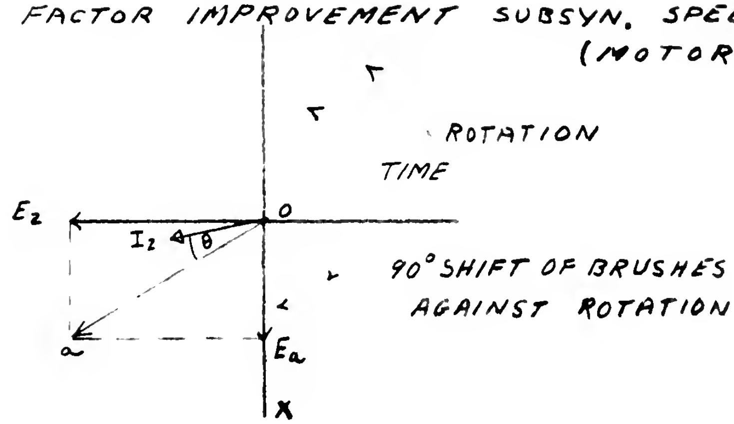


FIG 6

CIRCLE DIAGRAM ORDINARY INDUCTION MACHINE

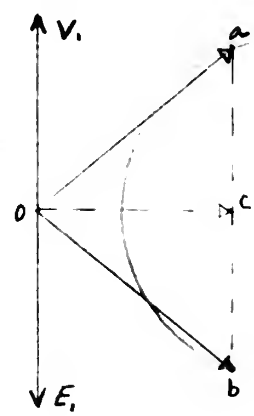


FIG 7

MOTOR VECTOR DIAGRAM, SUBSYN SPEED

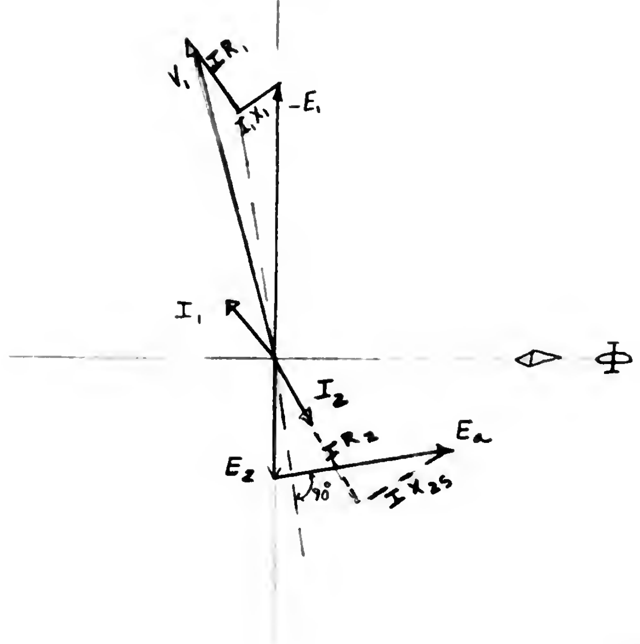


FIG 8

GENERATOR VECTOR DIAGRAM

SUPERSYN. SPEED

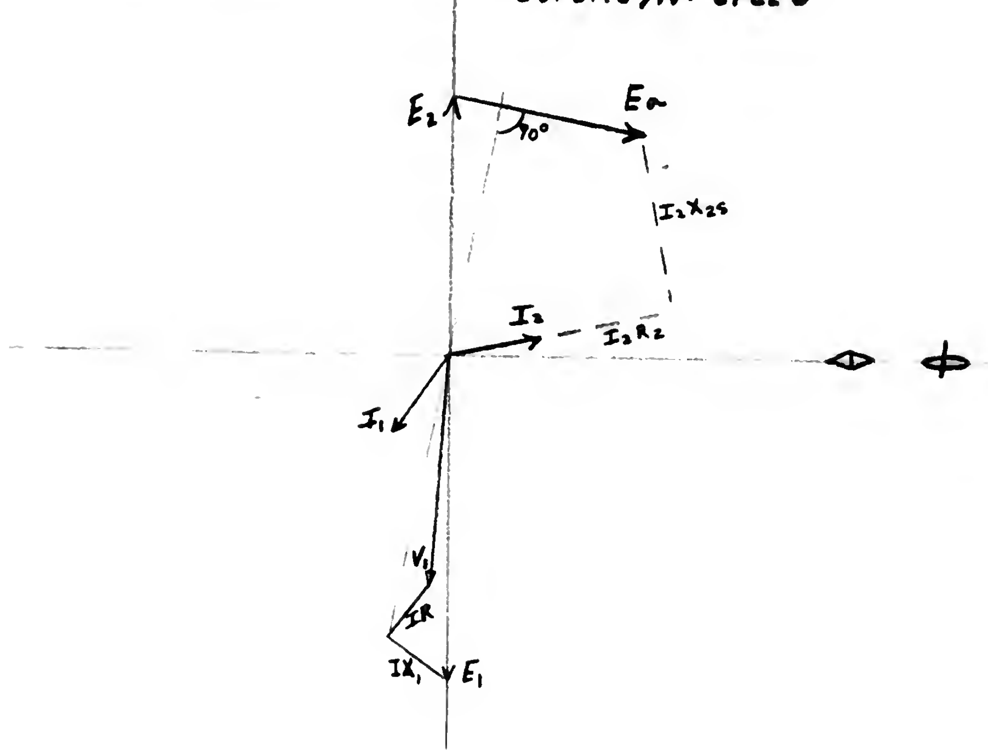
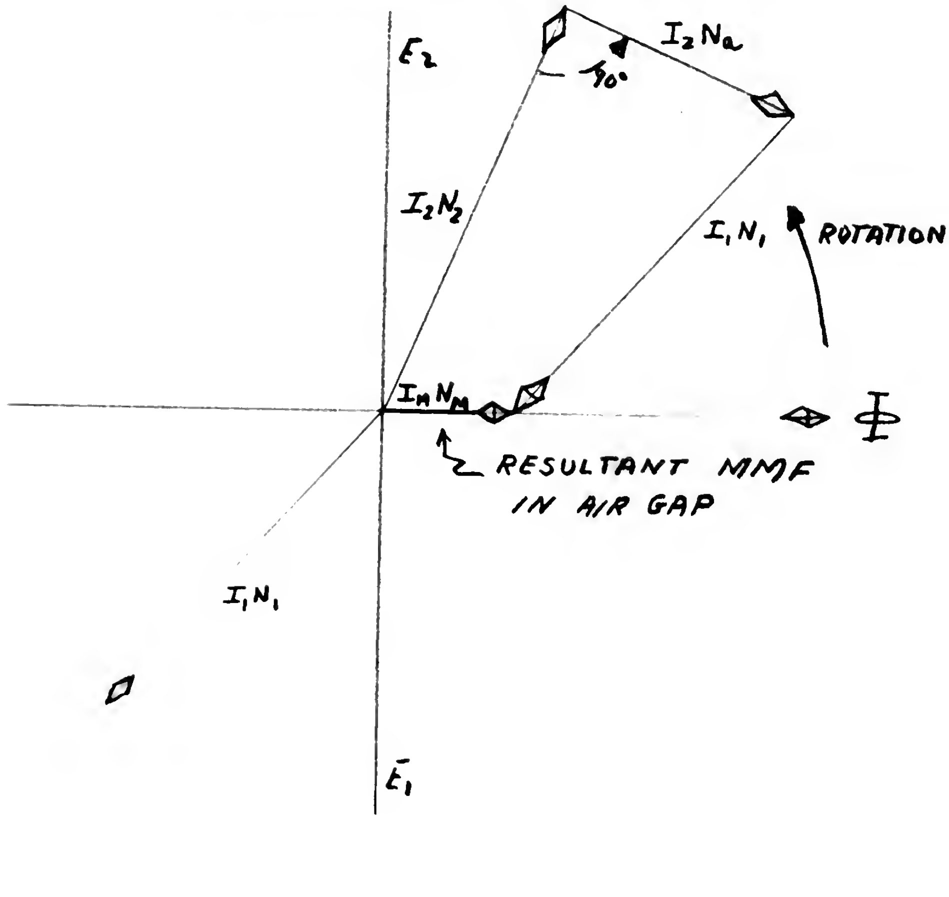


FIG 9

MMF DIAGRAM FOR GENERATOR



SUBSYNCHRONOUS

FIG 10

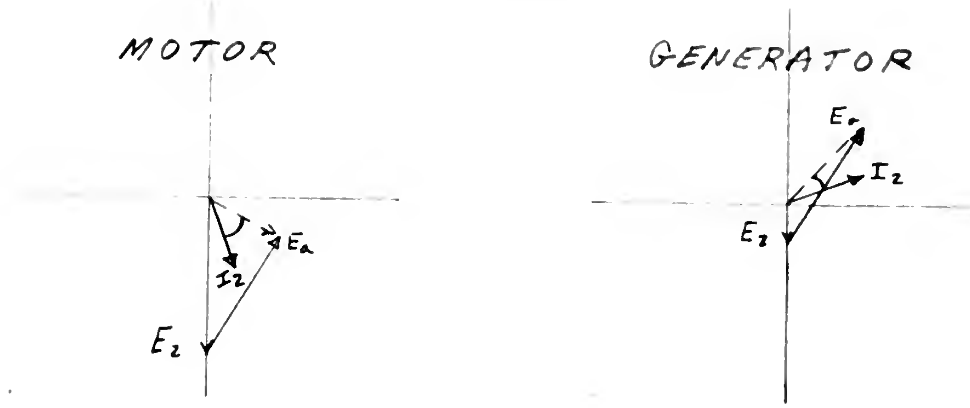


FIG. 11

90° SETTING

MOTOR ACTION SUBSYN., GENERATE SUPERSYN.

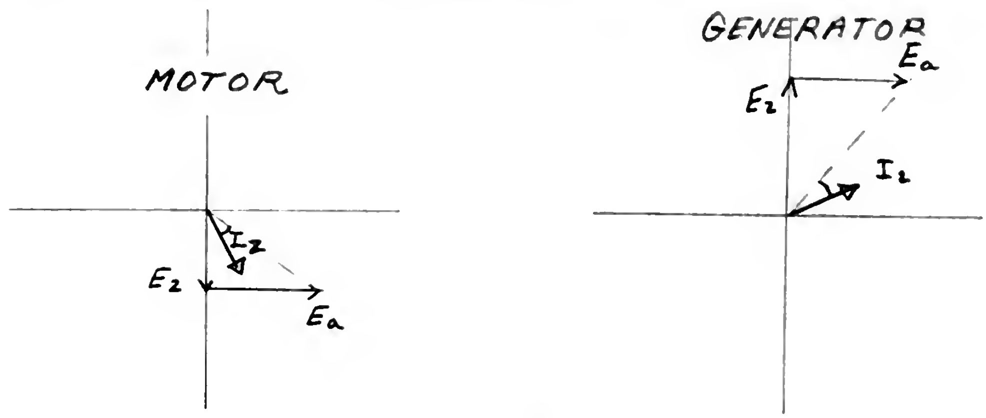
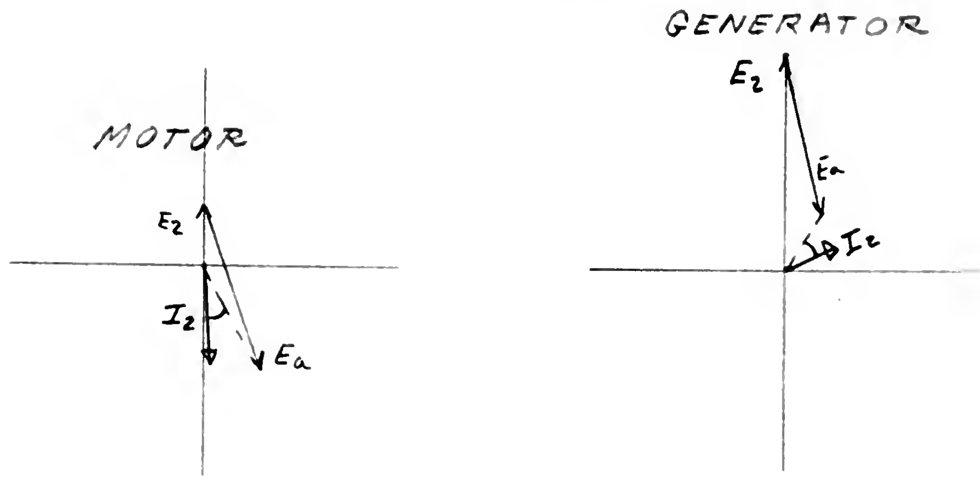
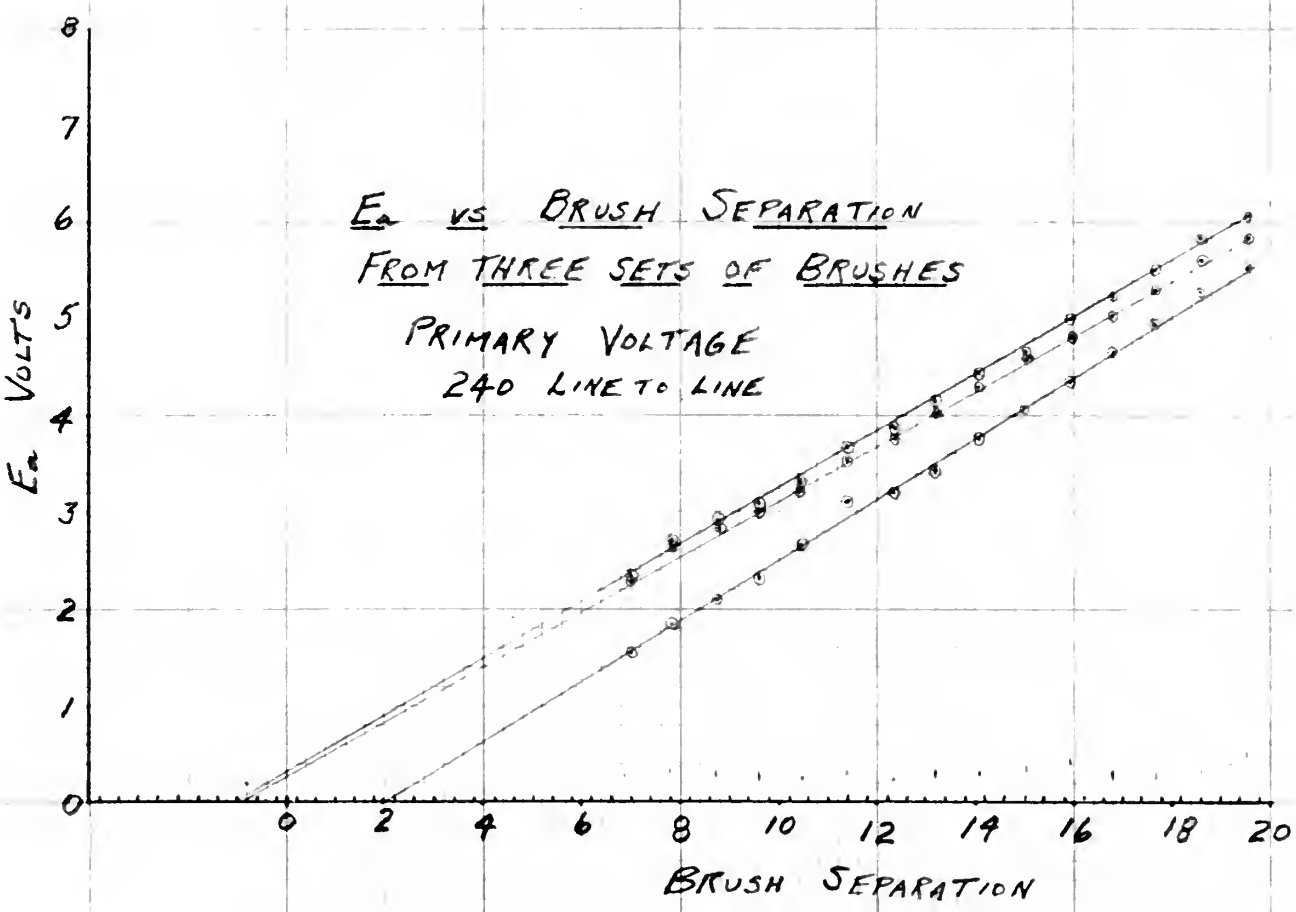


FIG. 12

SUPERSYNCHRONOUS





E_a vs Brush Separation
From three sets of Brushes
Primary Voltage
240 Line to Line
E_a Volts
Brush Separation
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
14
16
18
20

FIG 13

RUNS AT CONSTANT RPM = 1300

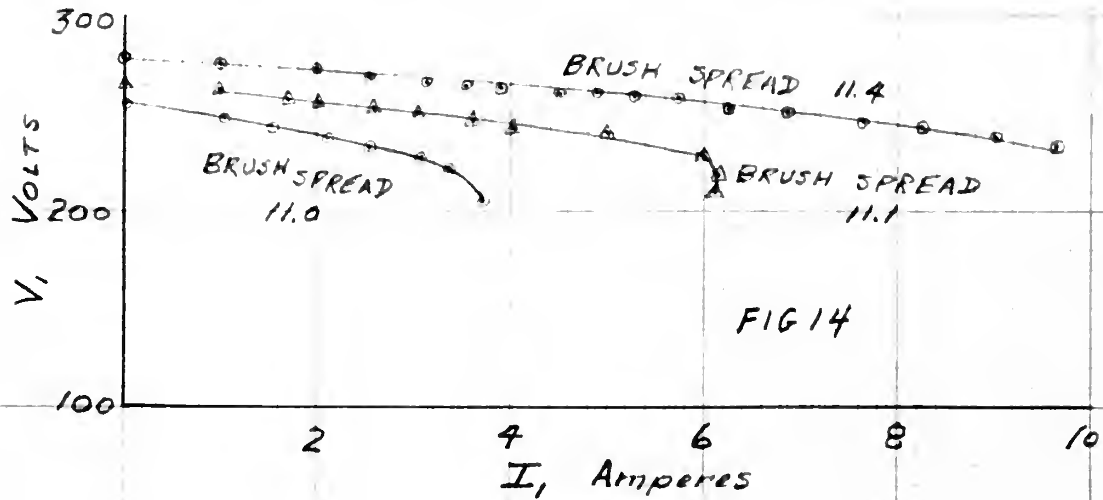


FIG 14

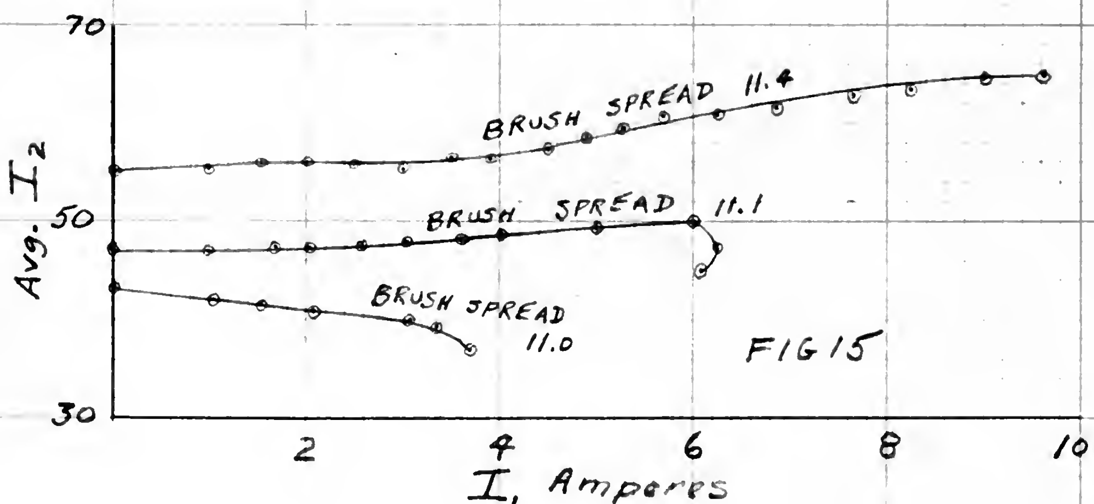


FIG 15

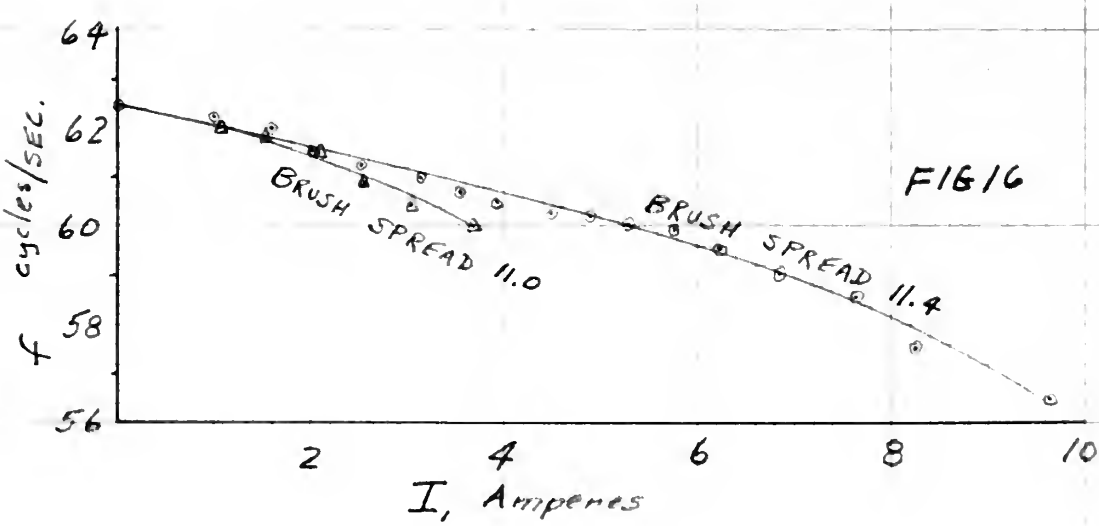


FIG 16

RUNS AT CONSTANT BRUSH SEPARATION $f = 60\sim$

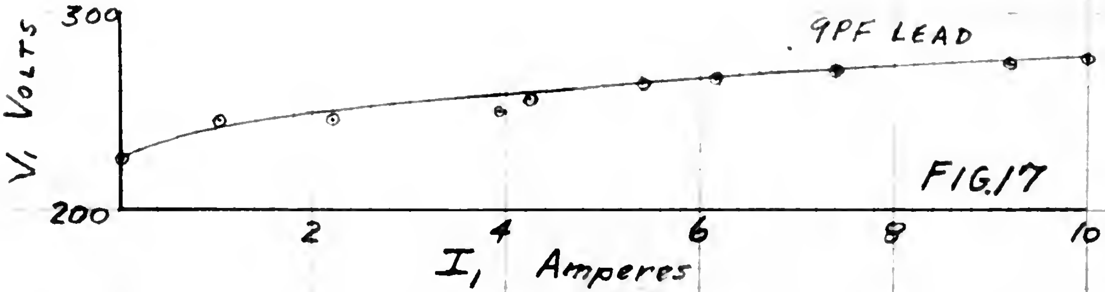


FIG.17

BRUSH SEPARATION 9.6

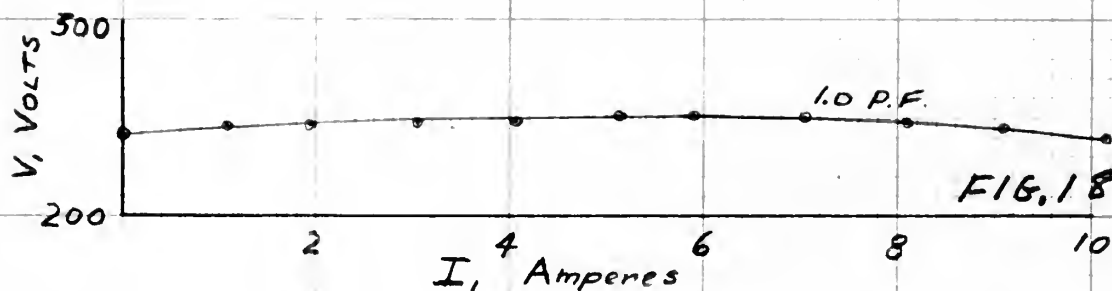


FIG.18

BRUSH SEPARATION 10.6

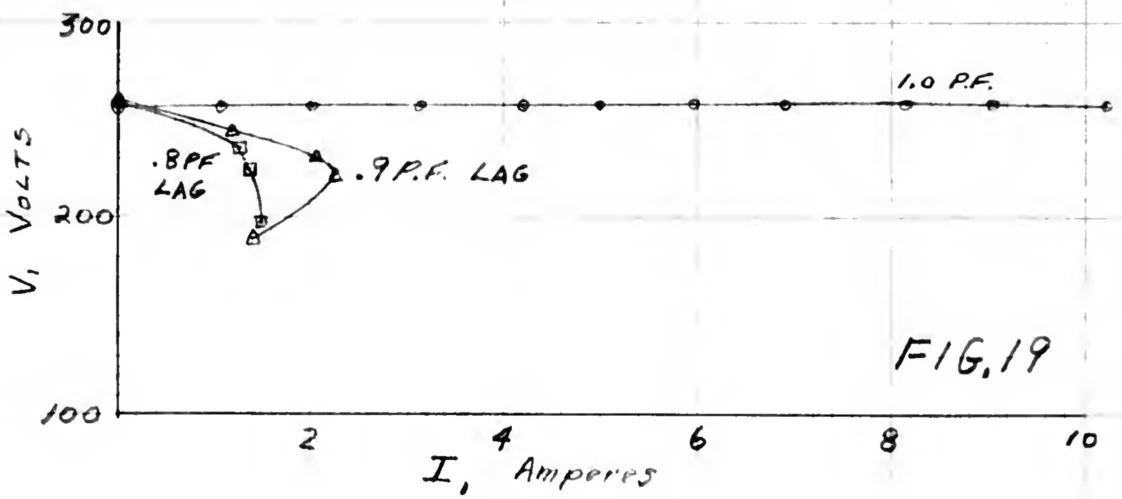


FIG.19

BRUSH SEPARATION 11.4

RUNS AT CONSTANT BRUSH SEPARATION f = 60~

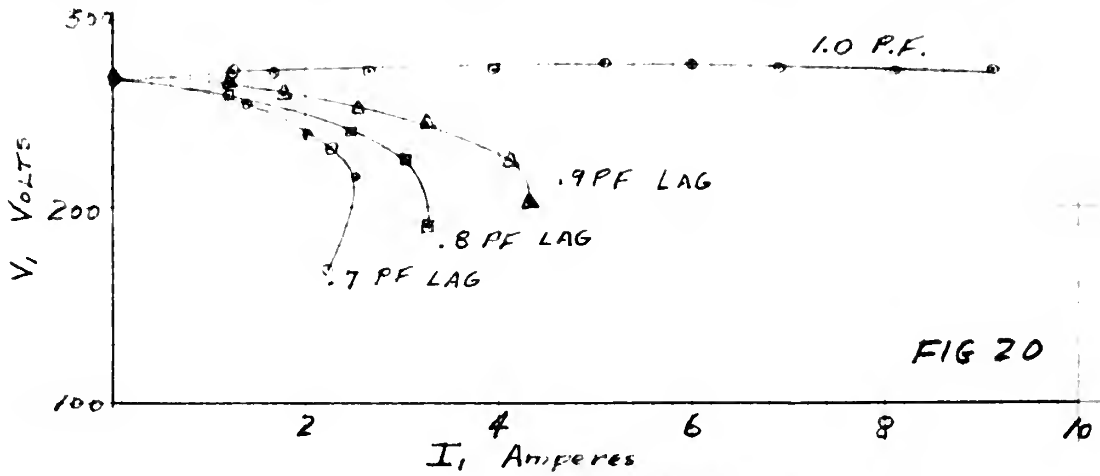


FIG 20

BRUSH SEPARATION 12.3

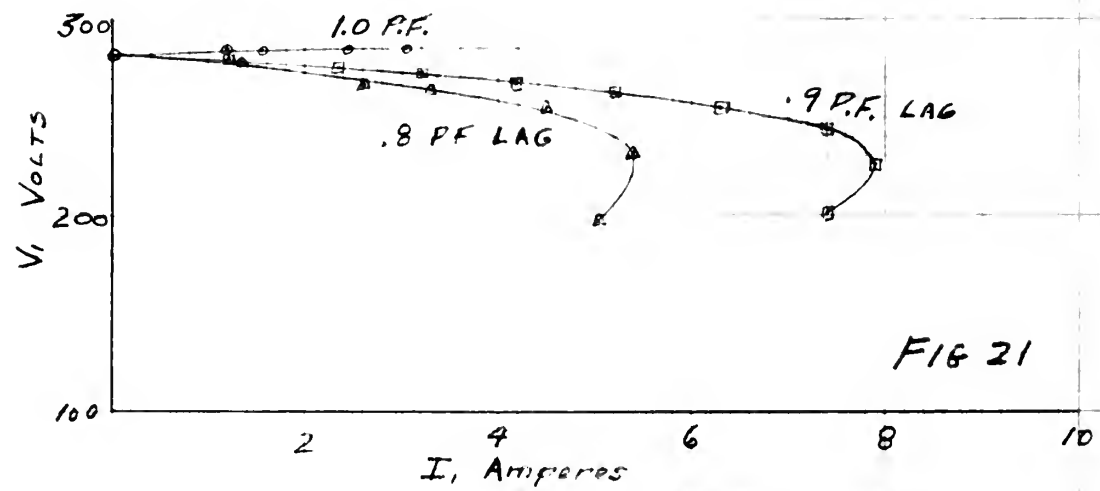


FIG 21

BRUSH SEPARATION 13.2

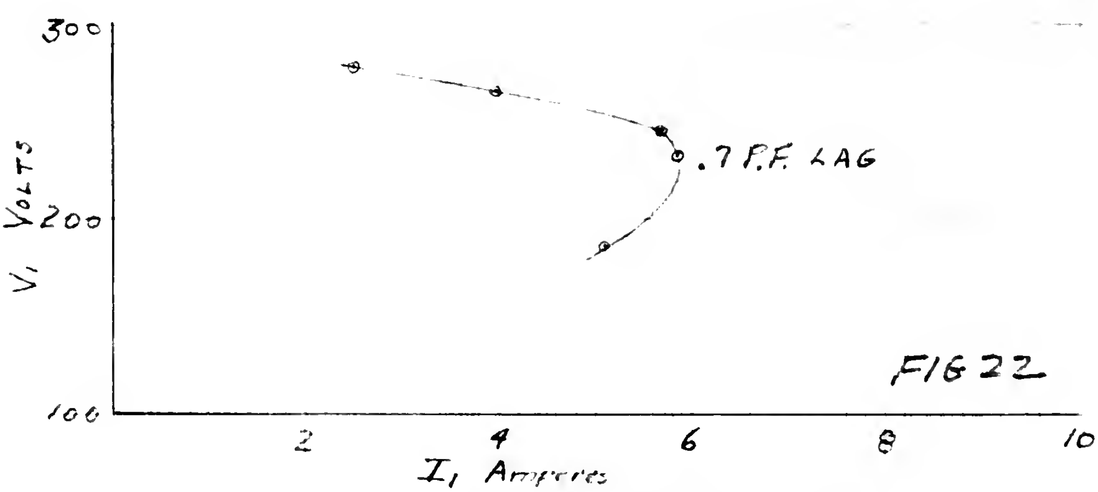


FIG 22

BRUSH SEPARATION 14.1

Independent Runs $V_1 = 240$ volts $f = 60\sim$

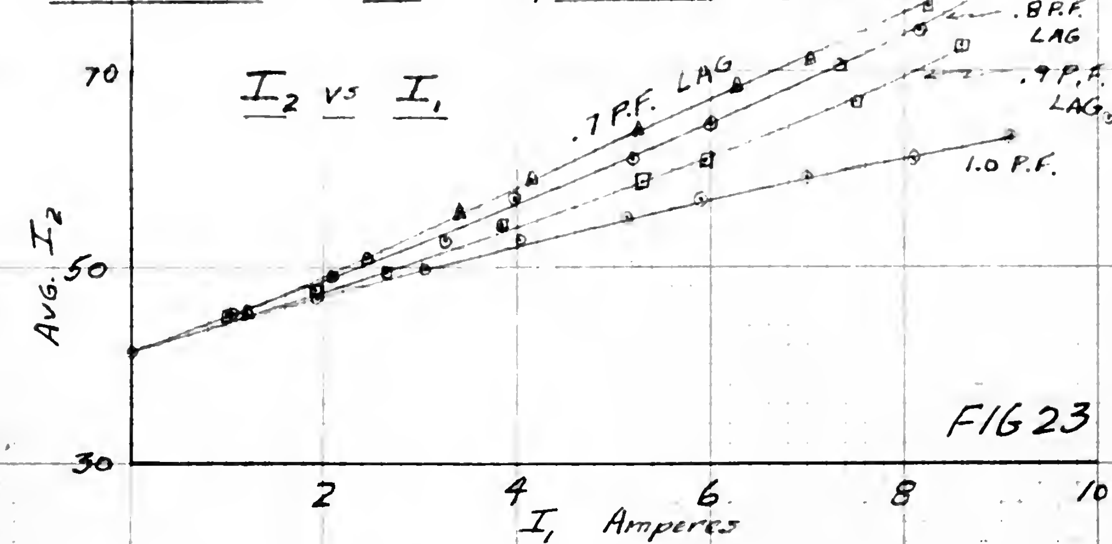


FIG 23

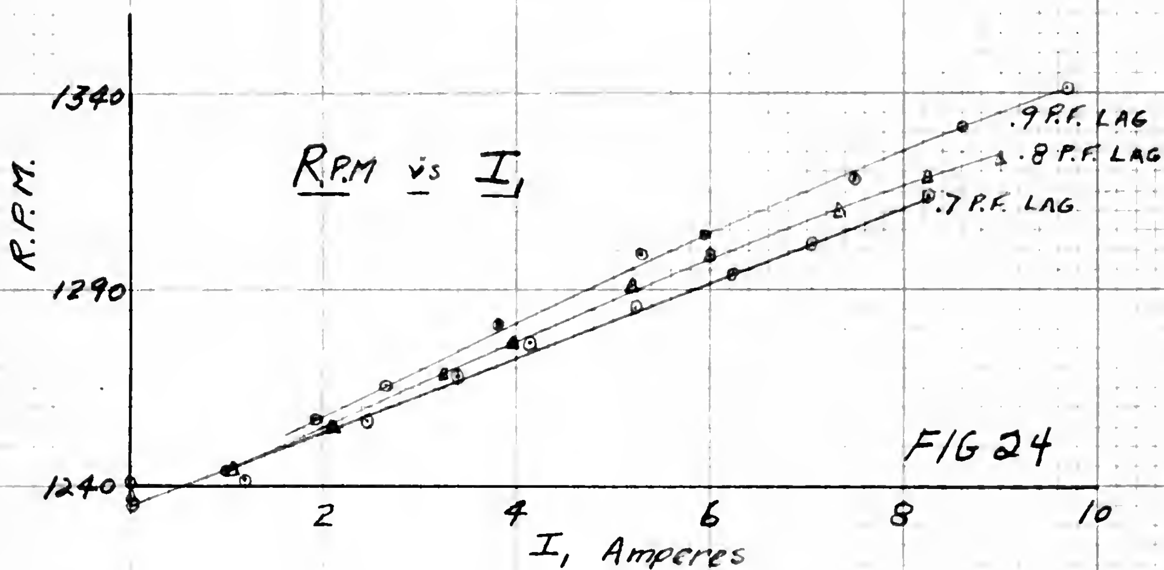


FIG 24

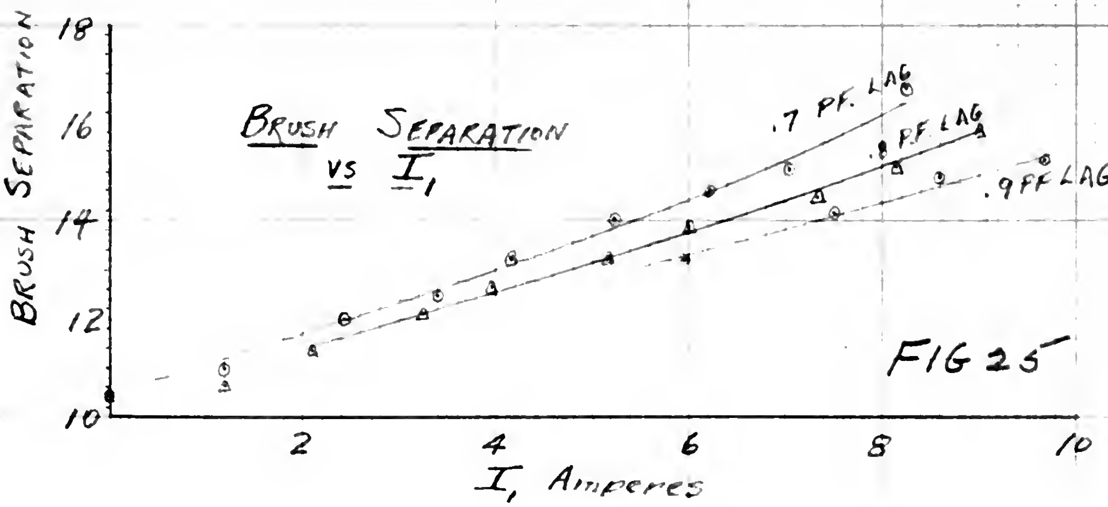
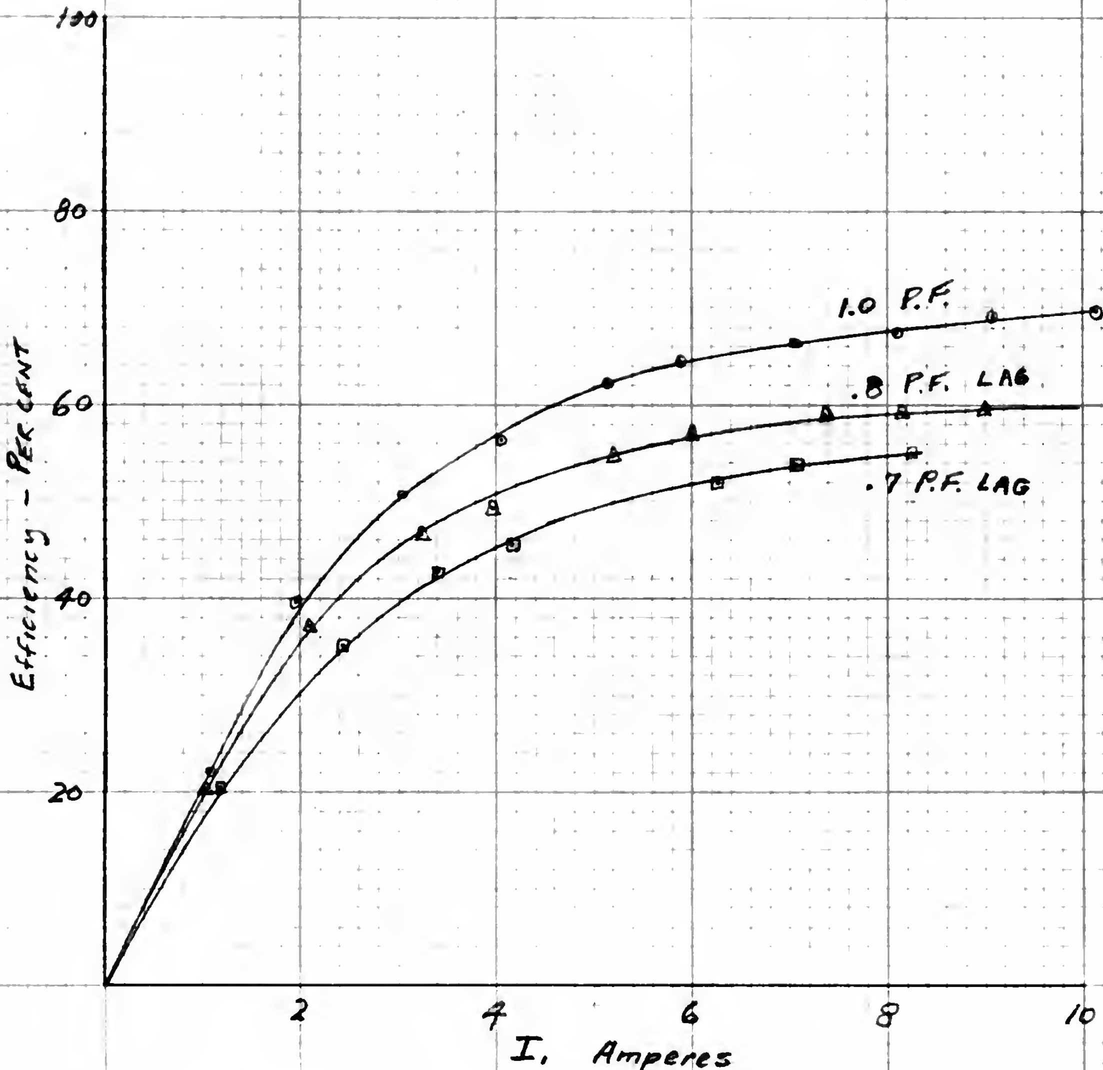


FIG 25



EFFICIENCIES OF INDEPENDENT RUNS

VOLTAGE CONSTANT = 240 VOLTS
FREQUENCY CONSTANT = 60 cycles/sec

FIG 26

FIG 27

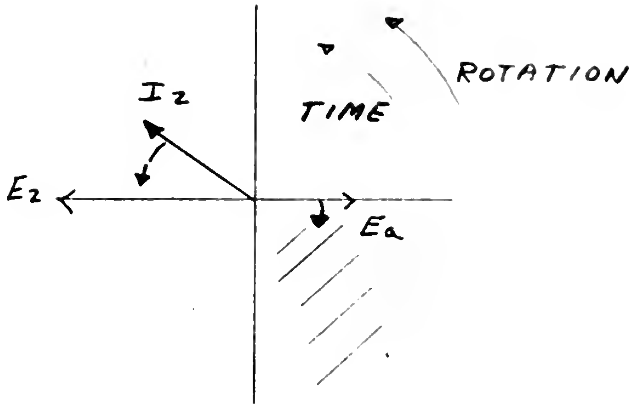


FIG. 28

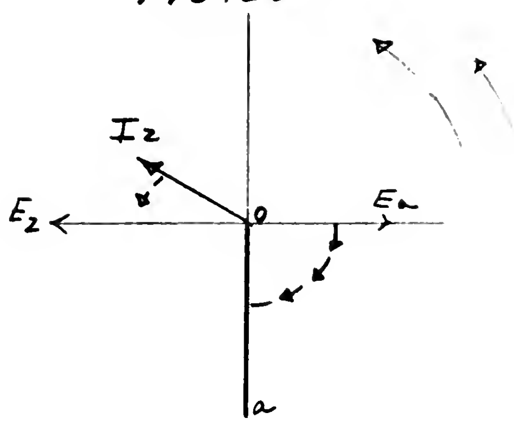


FIG 29

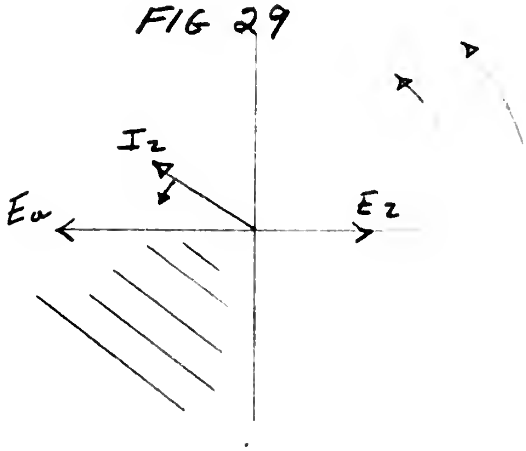
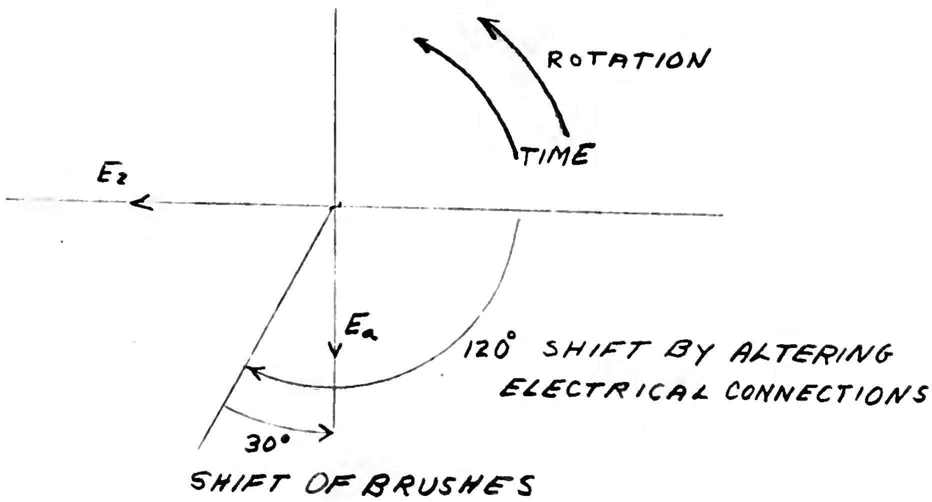


FIG 30


ROTATION
TIME
E_2
E_a
120° SHIFT BY ALTERING ELECTRICAL CONNECTIONS
30°
SHIFT OF BRUSHES

Thesis
B548 Blair 20597